EVALUATION OF RETROREFLECTIVE AIRFIELD PAVEMENT MARKINGS

ELLSWORTH AFB, SOUTH DAKOTA and TYNDALL AFB FLORIDA

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This report provides details on two tests performed to determine if 1.5 Index of Refraction (IOR) glass beads are suitable retroreflective material for USAF airfield markings. The tests were done at Ellsworth AFB SD from 28 Sep 91 through 9 Jun 92 and at Tyndall AFB FL from 12 Dec 93 through 24 March 95. During the first phase of the project, two taxiway centerline stripes, separated by a six-inch gap were applied on the primary aircraft taxi route at Ellsworth AFB SD.. Each was reflectorized with glass beads applied at approximately the same rate, but one was reflectorized using Federal Specification TT-B-1325B, Type I (1.5 IOR) beads and the other with Type III (1.9 IOR) beads. The test stripes were evaluated by 91 pilots and civil engineer personnel for approximately nine months through visual comparison and measurement of the retroreflective intensities of the two lines. The empirical data demonstrates the 1.5 IOR beads were more durable than were the 1.9 IOR beads. The pilots' evaluations showed that 1.5 IOR beads are suitable for airfield apron and taxiway markings. During the second phase of the project, the primary runway at Tyndall AFB FL was marked, again using the two different types of glass beads; however, these were procured under Federal Specification TT-B-1325C, an updated version modified to improve the performance of the Type III beads. The pavement markings applied on the north side of the runway centerline were reflectorized with Type I glass beads, and Type III glass beads were used to reflectorize the markings on the south side of the runway centerline. The test stripes were evaluated by 35 pilots and civil engineer personnel for approximately 15 months through visual comparison and measurement of the retroreflective intensities of the two lines. The empirical data demonstrates the 1.5 IOR beads performed slightly better than the 1.9 IOR beads. The surveys showed that 1.5 IOR beads are suitable for airfield runway markings.

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EXECUTIVE SUMMARY

1. Two tests were performed to determine if 1.5 Index of Refraction (IOR) glass beads are suitable retroreflective material for USAF airfield markings. The tests were done at Ellsworth AFB, South Dakota from 28 Sep 91 through 9 Jun 92 and at Tyndall AFB FL from 12 Dec 93 through 24 March 95.

2. At Ellsworth AFB SD, two taxiway centerline stripes, separated by a six-inch gap were applied on the primary aircraft taxi route. Each was reflectorized with glass beads applied at the same rate. One was reflectorized using 1.5 IOR beads, and the other with 1.9 IOR beads. The test stripes were evaluated by 91 pilots. Civil engineer personnel measured and tracked the retroreflective intensities of the two lines using a retroreflectometer. The empirical data demonstrates the 1.5 IOR beads were more durable than were the 1.9 IOR beads. The surveys showed that 1.5 IOR beads are suitable for airfield apron and taxiway markings.

3. At Tyndall AFB FL, the primary runway was marked using the two different types of glass beads. They were procured under a later version of the Federal Specification for retroreflective beads, TT-B-1325C. The updated version was modified to improve the performance of the 1.9 IOR beads. The pavement markings applied on the north side of the runway centerline were reflectorized with 1.5 IOR glass beads, and 1.9 IOR glass beads were used to reflectorize the markings on the south side of the runway centerline. The test stripes were evaluated by 35 pilots. Civil engineer personnel measured the retroreflective intensities of the markings using a retroreflectometer. The surveys showed that 1.5 IOR beads are suitable for airfield runway markings.

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RETROREFLECTIVE AIRFIELD MARKINGS

SECTION I -- INTRODUCTION

A. Scope

This report provides details on two tests to determine if 1.5 Index of Refraction (IOR) glass beads are suitable reflective material for airfields. The tests were done at Ellsworth AFB, South Dakota from 28 Sep 91 through 9 Jun 92, and at Tyndall AFB FL from 12 Dec 93 through 24 March 95.. Both tests were sponsored by the Air Force Civil Engineer Support Agency, Tyndall AFB FL. The Test Director was Mr Michael D. Ates.

SECTION II -- BACKGROUND

1. Historically, the United States Air Force has reflectorized airfield pavement markings to aid pilots in identifying the centerline, touchdown zone, and lateral limits of the runway. Taxiway and apron marking paints also contain glass beads for pilot visual cue enhancement. This was especially helpful to pilots during the early years of aviation before evolution of today's sophisticated lighting systems. This was accomplished by embedding glass beads into painted markings. The beads, made from scrap glass, were screened and graded during the manufacturing process to provide a mix of sphere sizes ranging from approximately 0.003 inch (0.076 mm) to 0.023 inch (0.584 mm) in diameter. The beads were spread on wet paint which was applied at a wet film thickness of about 15 mils (0.381 mm) so that approximately 50 percent of the largest diameter beads remained exposed. Then, during periods of darkness, light from aircraft landing/taxi lights would enter the beads and reflect the color of the underlying paint.

2. Over the years, as technology advanced, it became apparent that the reflective characteristics of glass beads could be improved by using higher density glass. As shown in Figures 1.a and 1.b, glass with a higher index of refraction (IOR) will more accurately focus, or bend, the incoming light ray to the true center of the bead. If the bead is properly embedded in a binder with good light reflecting characteristics, the light ray will be reflected back toward the surface of the bead very near the point of entry. This results in most of the light being reflected back to the source on a plane parallel with the incoming light ray (Figures 2.a and 2.b).

3. During the time when many runways lacked lighting systems, it was desirable to provide a marking which would return as much light as possible, as near to the source as possible, to increase the visibility of the marking to the pilot. A side benefit of using retroreflective materials with properties of the high IOR glass beads was to limit the area over which an aircraft's landing/taxi lights were dispersed by retroreflection. This reduced the probability that enemy observation pilots overhead might spot an aircraft taxiing on the ground. With this in mind, USAF commissioned development of a specification for beads manufactured from glass with an IOR of from 1.90 to 1.93. Until that time, glass beads manufactured from ordinary scrap glass with an IOR of from 1.50 to about 1.55 had been used to reflectorize pavement markings.

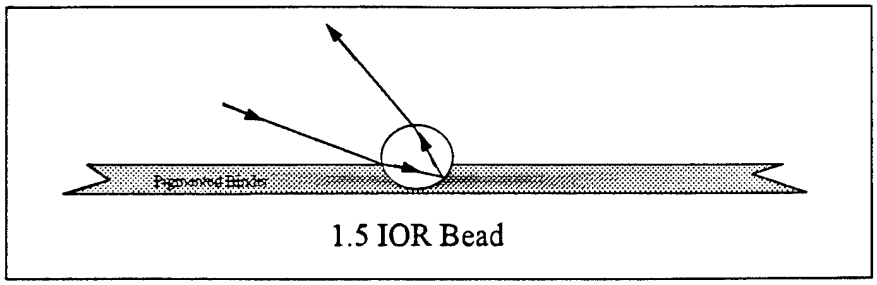
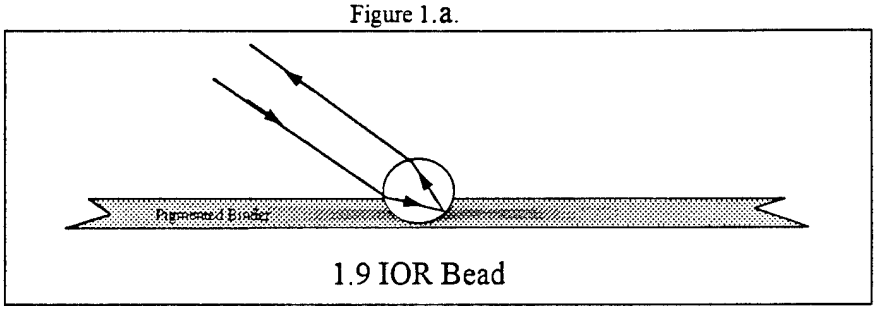


Figure 1.a.



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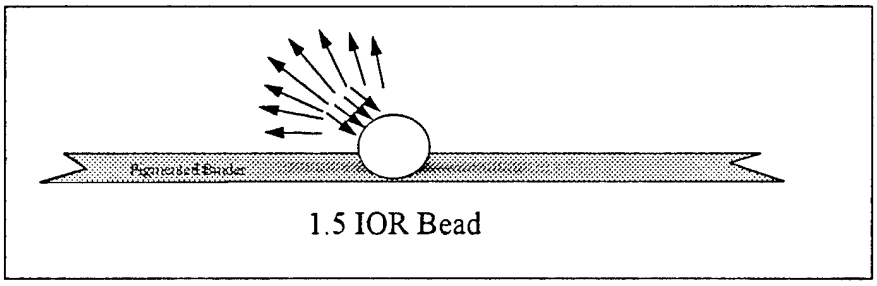

Figure 2.a.

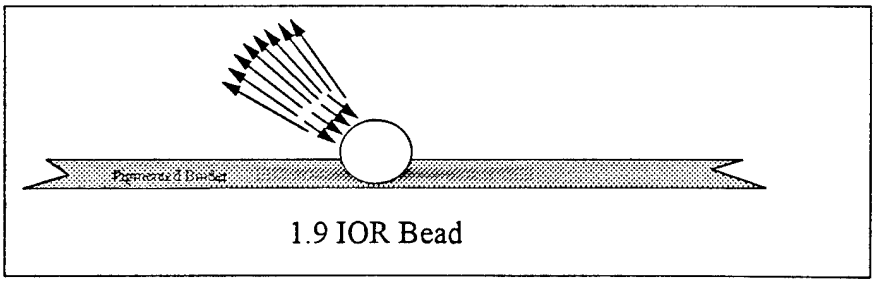

Figure 2.b.

SECTION III: TEST PROCEDURES

PHASE I

A. General:

1. Snow removal operations at northern tier bases such as Ellsworth AFB SD typically render the markings useless in less than a year. In Fiscal Year 91, the base lacked funding to remark the entire airfield with the more expensive 1.9 IOR beads. The base, supported by their Major Command's Flight Safety and Operations staff, requested a waiver to use the lower cost 1.5 IOR beads on their taxiways and aprons. This was necessary to accommodate remarking their taxiways and aprons. In light of the circumstances, AFCESA asked that they act as a test case for comparative analysis of markings reflectorized with both high and low IOR glass beads to determine if USAF was receiving full benefit from the high cost beads. Low IOR costs approximately 86 percent less than high IOR glass beads.

B. Test Procedures

1. In preparation for the test, a waiver was established through HQ Air Force Safety Agency and the USAF Instrument Flight Center, to allow deviation from marking standards. The waiver specifically required issuance of an Airfield Advisory and publication of a statement within the DoD Flight Information Publication cautioning of possible reduced retroreflectivity on the taxiways and aprons. The test marking scheme was also briefed to all resident and transient aircrew using Ellsworth AFB SD.

2. During this phase of the project, two taxiway centerline stripes were applied on the primary aircraft taxi route separated by a six-inch gap (see Figure 3). Each was reflectorized with glass beads applied at the same rate, but one was reflectorized using 1.5 IOR beads and the other with 1.9 IOR Beads.

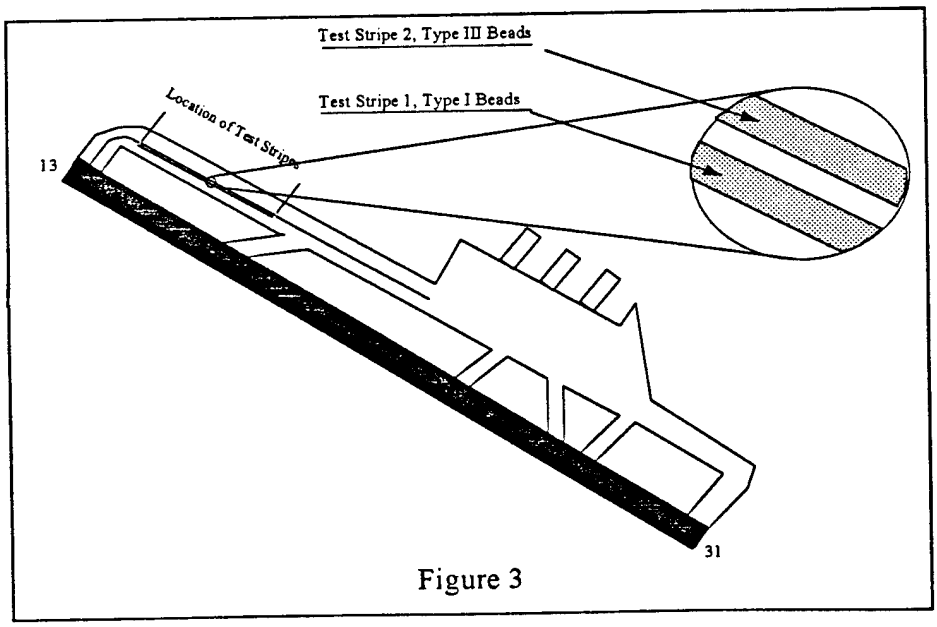

Figure 3

a. Prior to the application, the test area pavement was cleaned and the old taxiway centerline stripe was completely obliterated with a neutral color paint to ensure that no beads from prior applications remained exposed.

b. Also prior to the application, the paint and beads were sampled and inspected to determine their condition. Visual inspection revealed that both the unopened package markings and the physical characteristics of the contents were consistent with the requirements of the respective Federal Specifications for these materials. The samples were later tested for compliance with the respective Federal Specifications. Both the paint and beads were found to be in compliance.

i. The paint used met the requirements of Federal Specification TT-P-85E, 15 Sep 77, Paint, Traffic and Airfield Marking, Solvent Base[1].

ii. The glass spheres used met the requirements of Federal Specification TT-B-1325B, 25 Apr 78, Beads, (Glass Spheres) Retro-Reflective[2].

c. The application process was monitored to ensure the application rates were maintained at acceptable levels.

i. The wet film thickness of the paint was tested during the application to ensure proper bead retention in the marking. Both stripes were applied at between 13 and 15 mils.

ii. Samples of the paint, and paint with beads embedded, from each test stripe application were collected on acetate covered aluminum test panels to facilitate a visual inspection and validation of the paint and bead application rates. Bead quantities were also checked and verified to ensure adequate application rates.

iii. Immediately after application the test stripes were inspected to ensure proper dispersion of the beads across the stripe.

iv. After curing for approximately two hours, the marking samples taken on acetate were removed from the aluminum backing plate to facilitate visual inspection of bead dispersion through the cross section of the marking. The inspection revealed good dispersion across the markings as well as through the thickness of the paint.

d. Retroreflective measurements were taken initially, approximately two months later, and again nine months after the lines were installed. The results are tabulated at appendix A. The instrument used was a Mirolux 12, Serial Number 214. All readings are expressed in Mirolux 12 units.

e. The test stripes were visually evaluated by 91 pilots over nine months. The visual comparison data was gathered through administration of pilot surveys which inquired on the brightness of the two markings, time of day, type of weather, type of aircraft, and whether the landing/taxi lights were operating properly. The results are tabulated at appendices A and B.

SECTION IV: CONCLUSIONS AND RECOMMENDATIONS

PHASE I

A. Conclusions

1. At completion of the test, the test stripes had sustained approximately 22 passes of snow and ice removal equipment. The retroreflectivity of the 1.5 IOR markings had degraded approximately 11 percent from the initial value while the 1.9 IOR markings had degraded approximately 73 percent.

2. The reason the lower index of refraction material performed better is because the gradation of the 1.5 IOR media procured under Federal Specification TT-B-1325B is smaller and more uniform than that of the 1.9 IOR media. This is because it is intended for use on areas which are normally subjected to turning abrasion. This allows more of the 1.5 IOR beads to completely submerge in the wet paint film initially. Later, surface abrasion from tires or other means, such as snow removal equipment, exposes the smaller diameter beads, renewing the retroreflectivity of the marking. The 1.9 media[2] is screened to provide significantly larger average diameter spheres to provide high initial levels of retroreflectivity, since airfield markings are not normally subjected to turning abrasion. Hence, any significant amount of abrasion wears more of the 1.9 beads away in a shorter period of time, reducing the retroreflectivity and the service life of the marking.

3. After reviewing the results of the pilot questionnaires and the retroreflective readings taken from these markings, it was concluded that 1.5 IOR beads would be suitable for use on taxiways and aprons. This is particularly true with aircraft that have taxi/landing lights mounted away from the close proximity of the pilot's eye and line-of-sight. In this case, since there is more dispersion of light, (Figure 2) the pilot may actually see more reflected light from markings reflectorized with 1.5 IOR beads.

4. Ninety-one pilot questionnaires were collected during this evaluation. Review of the surveys revealed there was no overwhelming preference for either of the two test stripes even though the initial average retroreflective value of the 1.9 IOR marking was almost double that of the 1.5 IOR marking. In fact, more pilots chose the test stripe reflectorized with the 1.5 media as that which provided the best visual guidance.

a. Most pilots surveyed indicated a preference for one test stripe or the other, and all indicated that both were adequate for their intended purpose until the 1.9 IOR marking had deteriorated significantly. This leads us to believe that it may not be possible to distinguish a difference between markings reflectorized with the two types of beads from the cockpit of an airplane. This belief is due to the fact that landing/taxi lights are generally located on the wing or landing gear of the aircraft, some distance from the pilot's eye position and line-of-sight. This belief is affirmed through a test conducted by the Federal Aviation Administration's Technical Center, Atlantic City International Airport, NJ[3].

B: Recommendations

1. In Jun 92, the 28th Bomb Wing, AFFSA/IP and HQ AFCESA/DMP agreed to terminate the test due to the overwhelming results. The test participants at Ellsworth AFB SD provided their evaluation recommendations on 9 Jul 92[4].

a. Their report indicates that they achieved significant savings by substituting 1.5 IOR beads without detriment to operational safety. It also states that the majority of pilots surveyed

found the 1.5 IOR markings were equal to or better than the 1.9 IOR markings, and that the 1.5 IOR beads withstood weathering better than did the 1.9 beads.

b. The Base Civil Engineer, the Commander, 28th Operations Group, and the Commander, 28th Bomb Wing, all recommended USAF authorize use of 1.5 IOR bead reflectorized markings on all USAF taxiways and aprons.

2. HQ AFCESA/DM recommended revision of USAF's airfield marking material specifications to allow use of standard traffic beads (1.5 IOR glass) on Air Force taxiways and aprons in Jul 92[5].

a. The recommendation was approved by the USAF Flight Standards Agency[6], HQ USAF Safety Agency[7], HQ Air Force Communications Command[8], and HQ USAF/CEVP[9].

b. All USAF Major Command Civil Engineers and Base Operations personnel were notified of the change in material requirements on 6 Aug 92[10].

c. HQ USAF/CE/XOO approved publication of AFI 32-1042, Standards for Marking Airfields[11], 16 Mar 94, which published the change. This document provides standard marking criteria, material requirements and recommended application rates for both paint and beads used in USAF airfield applications.

3. The operational community recommended that we continue our efforts in this area and determine if the lower cost beads will suffice for runway markings.

SECTION V: TEST PROCEDURES
PHASE II

A. General:

1. The work at Ellsworth AFB SD increased interest in comparing the two different types of glass beads used to reflectorize USAF airfield markings. Numerous base and Major Command officials inquired informally of why the Type I material could not be used on runways. Rationale for not recommending this material for use on runways upon completing Phase I was simply that operational conditions in the runway environment are significantly different than operations on taxiways and aprons. Specifically, aircraft speeds are much higher and observation angles can be much different. Additionally, the result of the Phase I comparison clearly showed a need to improve the performance of the 1.9 IOR material.

2. On 15 Jul 92, HQ AFCESA/DM asked the General Services Administration to revise the Federal Specifications applicable to airfield marking materials[12]. Specifically, we asked that they modify both the water based paint specification[13] and the bead specification[2] to improve their performance.

a. Our request was based on findings reported from field work accomplished by the Naval Civil Engineering Laboratory, Port Hueneme CA, conducted between Oct 88 and Sep 91. Their work, although never completed, had given us reason to believe that the performance of the 1.9 IOR beads could be improved without degradation of the high retroreflectivity produced by this material, simply by reducing the average size of the individual beads. It also suggested that bead application rates could be reduced without degradation of the retroreflectivity.

b. On 1 Jun 93, the General Services Administration published revision "C" of Federal Specification TT-B-1325[14].

i. This increased the minimum percentage of spheres by weight required to pass U.S. Standard Sieve Number 18, from 80 percent to 100 percent. This requirement eliminates all spheres larger than 0.0394 inch in diameter from the gradation for the 1.9 IOR media.

ii.. This revision implemented an allowance for retention of up to five percent by weight of spheres at the U.S. Standard Sieve Number 20 (spheres larger than 0.0331 inch in diameter) where all spheres this size or smaller were allowed to pass previously.

iii. The revision changed the allowance for the percentage of spheres by weight for U.S. Standard Sieve Number 30, from a range of 30 percent minimum to 70 percent maximum, to a range from 55 percent minimum to 70 percent maximum. This increases the total quantity of spheres smaller than 0.0234 inch in diameter from as few as 30 percent to a minimum of 55 percent by weight.

iv. The revision implemented a requirement for at least 15 percent of the spheres by weight to pass U.S. Standard Sieve Number 40, and allows that up to 35 percent may pass. This increased the percentage of spheres smaller than 0.0165 inch in diameter from a maximum of five percent to a minimum of 15 percent.

v. This gradation allows a larger percentage of the spheres to fully embed in the binder. Additionally, since airfield marking paint is applied at between 12 to 14 mils for a dry film thickness of approximately seven to eight mils, a sufficient quantity of beads remain exposed on the surface to ensure a high level of immediate retroreflectivity.

3. Upon notifying USAF's Major Commands of the change in material requirements prompted by the Phase I test results, we began soliciting the Major Commands for a base to participate in evaluating the two different beads in the runway environment[10].

4. In July 93, we learned that Tyndall AFB would execute an airfield marking project in the near term.

a. We contacted HQ AETC/CEOE, the Major Command Civil Engineer's representative, the base civil engineer, the Operations Group Commander, and the Chief of Safety at Tyndall to solicit their support for the Phase II evaluation.

b. Upon gaining command and base level approval, we asked the U.S. Air Force Safety Agency, and the U.S. Air Force Flight Standards Agency's Instrument Flight Center and Air Traffic Services Center to help us develop a test plan and establish a waiver to conduct the follow-on evaluation of the two different types of beads using the latest bead specification. [15]

c. By 3 Aug 93, all agencies agreed to establish the waiver and proceed with the evaluation. [16]

B. Test Procedures

1. The test hypothesis was that 1.5 IOR beads would provide adequate visual cues for all weather operations. It was understood that since 1.9 IOR beads provide more reflected light back to the source, that in any situation where the pilot's eye is coincident with the source, these beads would be more visible. However, in most cases, when aircraft are near enough to runway markings for the reflected light to be usable, their eye position is no longer coincident with the light source. In this case the greater scatter of light from the 1.5 IOR beads may make them as usable as 1.9 IOR beads. With this in mind, our test objective was to prove whether or not 1.5 IOR beads are acceptable for use on USAF runways.

a. The test plan was to mark approximately half of the primary Category II runway (13L/31R) at Tyndall AFB FL with FED SPEC TT-B-1325C, Type I beads (1.5 IOR), and the other half with FED SPEC TT-B-1325C, Type III beads (1.9 IOR). Both were installed using waterborne paint manufactured under the U.S. Navy's Public Works Specification (PWC) DS-1952B, Paint, Traffic and Airfield Marking, Water Base[17].

b. The specific areas to be marked with each different type beads were:

i. Type I (1.5 IOR) beads; all threshold, touchdown zone, and fixed distance markings to the left of centerline on runway 13L (north side) for the entire length of the runway, and all centerline stripes from the 7,000 feet Runway Distance Marker (distance remaining) to the 3,000 feet Runway Distance Marker (see Figure 4).

ii. Type III (1.9 IOR) beads; all threshold, touchdown zone, and fixed distance markings to the left of centerline on runway 31R (south side) for the entire length of the runway, and the first and last 3,000 feet of centerline stripes for both approach headings (see Figure 4).

c. In order to obtain the best representation of the overall condition of the markings throughout the test period, we selected areas frequently subjected to turning abrasion which seldom accumulate any rubber build-up, areas frequently subjected to landing impact which usually accumulate the greatest amount of rubber build-up, and areas frequently subjected to normal rolling traffic which are rarely subjected to turning abrasion or rubber accumulation. The specific areas selected for retroreflective measurement were:

i. threshold markings;

ii. fixed distance markings;

iii. touchdown zone markings located 1,500 feet from each threshold;

iv. a segment of centerline stripes located from between 2, 580 feet to 3,000 feet from the threshold on runway 31 Right, and;

v. a segment of centerline stripes located from between 3,000 feet to 3,420 feet from the threshold on runway 13 Left.

d. The retroreflective value for each of these areas were measured and recorded initially, and at approximately four month intervals for the duration of the test. On three occasions, performance of the readings was delayed due to runway construction, rain and/or limited access to the runway due to mission requirements. The time elapsed between 1 May 94 and 31 July 94 was not counted as an in-service period for the markings because no aircraft operations were conducted on the runway during this time. Therefore, the third inspection was delayed to allow an average number of normal aircraft operations before the retroreflectivity readings were taken again.

i. The 1.9 IOR markings were installed and the retroreflective values measured on 12 Dec 93.

ii. The 1.5 IOR markings were installed on 13 Dec 93, and the retroreflective values measured on 28 Dec 93.

e. These readings established our base-line for the overall retroreflective value of both the 1.5 IOR and the 1.9 IOR markings. The retroreflective values were again measured and recorded on 5 May 94, 27 Oct 94, and 24 Mar 95. The results are tabulated and plotted at Appendix C.

f. During execution of the contract to mark runway 13L/31R, we monitored the installation of all markings. We also visually inspected all materials each time the application equipment was loaded to ensure they were in good condition and that the appearance was consistent with the physical characteristics of the material specified for the project. We also collected samples of the beads for laboratory tests, application samples of paint, and application samples of paint with beads embedded.

i. The beads applied to the markings on the north side of centerline, and on the middle 4,000 feet of centerline stripes on runway 13L/31R complied with the gradation and specific gravity requirements of Federal Specification TT-B-1325C, Type I[14].

ii. The beads applied to the markings on the south side of centerline, and on the first 3,000 feet of centerline stripes on runway 13L/31R complied with the gradation and specific gravity requirements of Federal Specification TT-B-1325C, Type III[14].

iii. Paint application samples were collected on bare aluminum panels to allow determination of the wet film thickness. These samples were taken randomly during the application process, and each time the equipment was adjusted (average speed or pressures), or replenished with materials. In this way we were able to ensure the paint application rate was maintained at between 13 and 15 mils wet film.

iv. Application samples of paint only, and paint with beads embedded were collected on acetate covered aluminum panels. Upon curing, these samples were removed from the aluminum panels, and visually inspected for uniformity of application. Afterwards, they were used to estimate the application rate for comparison with material consumption data gathered during the project.

g. The total quantity of materials consumed and the total area marked on runway 13L/31R were as follows:

i. white paint[17] -- 660 gallons

ii. 1.5 IOR beads[14] -- 1.50 pallets (60 bags or 3,000 pounds)

iii. 1.9 IOR beads[14] -- 2.50 pallets (90 bags or 4,500 pounds)

iv. 1.5 IOR markings --31,800 square feet.

v. 1.9 IOR markings -- 36,600 square feet.

h. We also administered pilot questionnaires over the course of the evaluation which inquired on the usefulness of the two markings. The questionnaire also asked the time of day, type of weather, type of aircraft, type of approach flown (i.e. precision instrument, night VFR etc.), approach heading, and whether the landing/taxi lights were operating properly. The results of the surveys are tabulated and plotted at Appendix D.

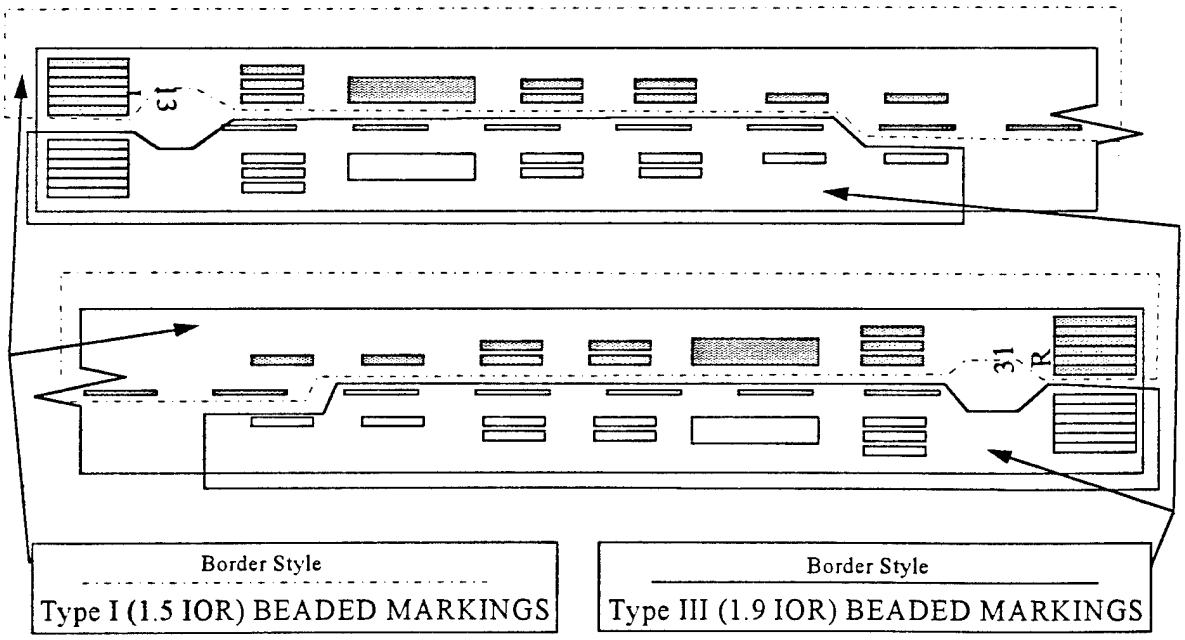

Figure 4

SECTION VI: CONCLUSIONS AND RECOMMENDATIONS

PHASE II

A. Conclusions

1. At completion of the test, the test markings had sustained approximately 15,000 aircraft take-off and landing operations. Upon collecting the last set of retroreflectivity readings, the overall condition of the markings appeared good with moderate to heavy rubber build-up in the center 60 feet of the runway from about 700 feet from each threshold to about 2,000 feet from each threshold. If a rubber removal maintenance program were implemented which would not remove the paint, these markings could provide good service for an undefined period, perhaps as much as three years.

2 At this point in the evaluation, the average retroreflectivity of the 1.5 IOR markings had increased approximately 22 percent from the initial value established by the readings taken on 28 Dec 93. The retroreflectivity of the 1.9 IOR markings had also increased, but only about 14 percent from the initial value established on 12 Dec 93 (see Figure 5).

a. We believe the reason the retroreflectivity of the 1.9 IOR beaded markings did not increase as much as the 1.5 IOR beaded markings is the 1.9 IOR beads are not as durable as the 1.5 IOR beads[18].

b. Minor damage to the inner edges (approximately two feet) of the touchdown zone and fixed distance markings occurred during a construction project to replace the slabs on the outside edge of the runway keel. The damage was caused either by the slurry spill-over common during the pouring process, or from the curing compound used. The damage occurred during the closure from 1 May 94 to 31 Jul 94. This condition was noted while performing a visual inspection prior to taking the retroreflective readings on 27 Oct 94. To prevent this condition form impacting the test, the damaged areas were avoided by relocating the instrument approximately four feet inboard form the inner edge of the markings while taking readings.

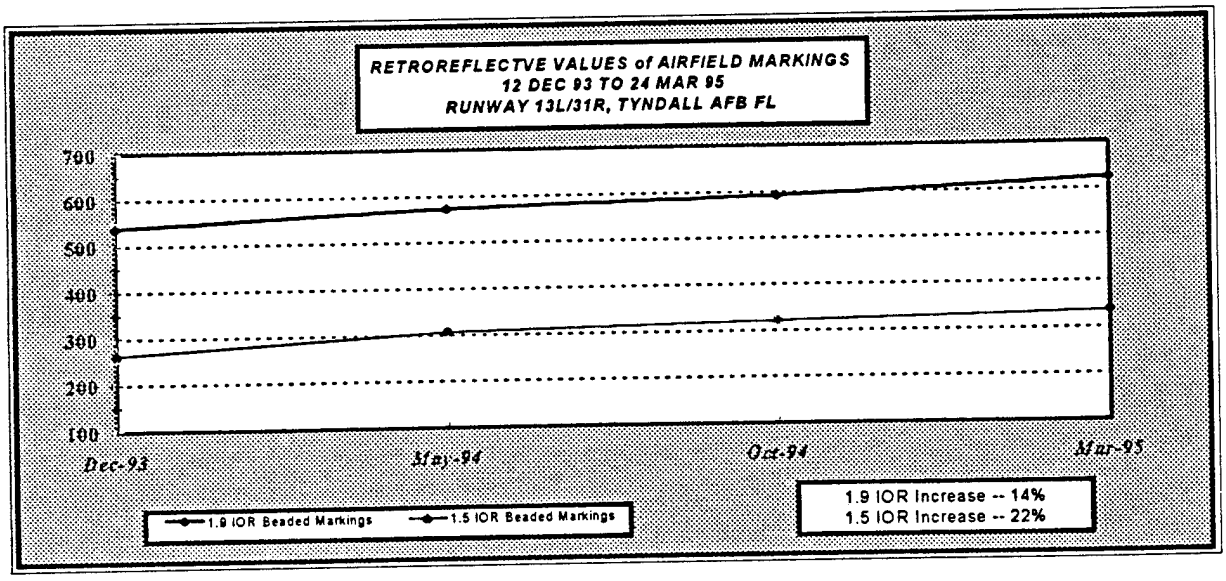

Figure 5

3. Although we attempted to control the bead application rates to assure identical quantities of paint and beads were applied for both sets of markings, we did not succeed.

a. In our estimation the application rate of the beads varied from as few as approximately 5.829 pounds per gallon of paint for the 1.5 IOR markings to as high as 21.780 pounds per gallon of paint for the 1.9 IOR markings.

i. Weight comparisons of the 1.5 IOR beaded and unbeaded acetate-backed samples suggest that the average bead application rate for these markings ranged from 5.429 to 5.829 pounds per gallon of paint.

ii. Calculation of the total quantity of materials used vs the area marked with the 1.5 IOR beads suggests an application rate of approximately 9.836 pounds per gallon of paint..

iii. Weight comparisons of the 1.9 IOR beaded and unbeaded acetate-backed samples suggest that the average bead application rate for these markings ranged from 16.577 to 21.780 pounds per gallon of paint

iv. Calculation of the total quantity of materials used vs the area marked with the 1.9 IOR beads suggests an application rate of approximately 12.820 pounds per gallon of paint.

b. Review of the individual retroreflectivity readings does not reveal increased or decreased retroreflective values in the areas where the application rates varied the widest. Therefore, we concluded that the variation in the bead application rates was not a factor for the purpose of this evaluation. It appears that increasing the quantity of beads applied above a given threshold will not increase the retroreflective value of the marking. However, it may increase the skid resistance and/or the rate of improvement in the retroreflectivity of the marking as the paint abrades over time.

c. The difficulty in applying the specified quantity of beads for the area marked is greatly affected by the gradation and specific gravity of the material used. Even though the contractor had extensive experience in applying both types of beads, we concluded that more 1.9 IOR beads were applied than was specified because of inexperience with this finer gradation of beads of the same mass, but less volume.

i. This was the first USAF marking application using revision "C" of Federal Specification TT-B-1325.

d. Because the contract specified ten pounds of beads per gallon of paint for both the 1.5 and the 1.9 IOR beads, the contractor adjusted his bead dispensers to the highest possible setting while applying the 1.5 IOR beads.

i. This is because these type beads have a much lower specific gravity than the 1.9 IOR beads and therefore, one must apply almost twice the volume of 1.5 beads to achieve the same rate of application as 1.9 IOR beads when the application is specified for the contractor to place a given weight of beads per gallon of paint.

ii. The specific gravity of the 1.5 IOR beads ranges from 2.30 to 2.50.

iii. The specific gravity of the 1.9 IOR beads ranges from 4.00 to 4.50.

4. Review of the pilot questionnaires collected during this evaluation demonstrates that 94 percent of the pilots surveyed could not distinguish a difference in the two different types of beads.

a. Specifically, the pilots were advised that the markings on either side of centerline for the entire length of the runway were reflectorized using two different types of beads. The questionnaire offered them an opportunity to identify any markings which they felt were unsuitable for the intended purpose, any other comments, and inquired of

i. aircraft type and operating condition of the landing/taxi lights;

ii. approach heading of the runway used;

iii. date and time of day;

iv. weather conditions;

iv. type of approach flown.

b. Of 35 surveys completed, one pilot flying night visual flight rule in clear weather indicated the 1.5 IOR markings were not adequate during approach but were no different than the 1.9 IOR beaded markings after touchdown.

c. Another indicated the 1.5 beads did not provide an adequate level of retroreflectivity during approach or after landing. The pilot's specific comment was; "I could tell the difference between the left and right runway."

i. This particular survey was completed on a clear day under visual flight rule at 1200 hours local time, 7 Jan 94. It should be noted that at that time of day and year, the sun is in the southern sky. Since both runways (13L/31R and 13R/31L) are oriented more east to west, the pilot probably observed reflected light from the painted surfaces of runway 13R, the adjacent parallel runway, rather than retroreflection from his landing lights on runway 13L.

d. One additional survey gave no indication of the pilot's perception of the markings during approach, but did indicate no difference was noticed in any section of centerline stripes.

e. There were seven different types of aircraft flown during these evaluations. However, comparison of the results focusing on this aspect of the evaluation as the prime factor did not reveal any pattern to indicate that the pilot's perception of the retroreflectivity was dependent upon the type of aircraft operated. The type, date, and number of various aircraft used during the evaluations are tabulated at Appendix D.

f. The dates of the pilot evaluations were dispersed across the evaluation period providing a good data base with relation to the condition and retroreflective value of the markings as time passed.

i. No pattern of inadequacy or perceived degradation was detected while reviewing the questionnaires except two general comments regarding the centerline stripes in the first 2,000 feet of both runways. These areas were marked using 1.9 IOR beads. Since the retroreflective readings in these areas were consistent with those produced by good markings reflectorized with 1.9 IOR beads, and because visual inspection of these areas revealed moderate rubber build-up with no mechanical failure of the centerline stripes, we concluded the comments resulted from rubber build-up in the touchdown area. These two evaluations were accomplished in April and August of 1994.

g. We asked that the evaluations be conducted during periods of daylight and darkness, and that the pilots indicate the weather condition during their approach. Evaluation of

the results revealed no correlation of reduced effectiveness during any specific weather condition or conditions.

i. Of the 35 evaluations conducted, 20 (74 percent) were conducted at night. Six (17 percent) of these were flown in rain. The survey comment mentioned in paragraph 4.b above, indicating the inadequacy of the 1.5 IOR beaded markings prior to touchdown was the only indication of a possible deficiency. All others, including those performed during rain, indicated they perceived no difference in the 1.5 and 1.9 IOR markings.

ii. The remaining nine (26 percent) were conducted under day visual flight rules.

h. We asked that the pilots indicate whether or not their landing/taxi light were working properly. Of the 35 questionnaires collected, 31 pilots (89 percent) indicated they were, three did not respond to the question, and the pilot of the C-172 indicated that the question was not applicable.

i. We also solicited general comments from those evaluating the markings. These helped to clarify some of the incomplete responses and provided some additional insight as to the visual range of the markings in clear weather. The pilot's general comments are listed with the other questionnaire data at Appendix D.

B: Recommendations

1. Recommend USAF change the airfield marking material standard to allow use of 1.5 IOR beads on all areas of the airfield, including runways and helipads.

a. The 1.5 IOR beads should be placed with a high quality binder at the following application rates:

i. Waterborne paints applied at from 12 to 14 mils wet film thickness should have Federal Specification TT-B-1325, Type I beads applied at a minimum rate of six pounds per gallon of paint. These markings should be required to produce a minimum initial retroreflective reading of 250 when measured with a Mirolux 12 Retroreflectometer or an equivalent instrument.

ii. Thermoplastics, epoxies, and other 100 percent solids materials used for taxiway and apron applications should be applied in accordance with the manufacturer's recommendations, but the bead application rate must be adjusted to provide a minimum of 0.05 pound of beads per square foot marked for each 8 mils of marking film thickness. For thermoplastics, a portion of the beads equivalent to that recommended for painted markings above must be post applied to the surface of the marking to provide initial retroreflectivity.

2. In cases where 1.9 IOR beads are used, recommend reducing the specified application rate to a minimum quantity of eight pounds of beads per gallon of paint, and addition of a requirement for the marking to produce a minimum retroreflective value of 500 when measured with a Mirolux 12 Retroreflectometer or an equivalent instrument.

GLOSSARY

Airfield Advisory -- Advice and information provided by a facility to assist pilots in the safe conduct of flight and aircraft movement.

Airfield Markings -- Markings of specific size, shape, and color, painted or formed on the pavement to provide information intended to aid to pilots during take-off, landing and taxiing operations.

Index of Refraction -- The ratio of the velocity of radiation in the first of two media to its velocity in the second as it passes from one into the other.

Reflectorized -- To make reflective or retroreflective.

Retroreflective -- The property of a material that indicates its ability to reflect light so that the paths of the rays are returned to the source on a plane parallel to the incident rays.

Retroreflectometer -- A device for measuring the reflectance of radiant energy.

REFERENCES

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2. Federal Specification TT-B-1325B, Beads (Glass Spheres) Retro-Reflective, April 25, 1978.

3. Evaluation of Retro-Reflective Beads in Airport Pavement Markings, U.S. Department of Transportation, Federal Aviation Administration, FAA Technical Center, Atlantic City International Airport, N.J., Dec 94.

4. 28 BW/CC Letter to HQ AFCESA/DMP, Subject; Final Evaluation and Recommendation of Ellsworth AFB Taxiway and Apron Marking Test, 9 Jul 92.

5. HQ AFCESA/DM Letter to HQ USAF/CEVP, USAF IFC/IP, HQ AFSA/SEFA, and HQ AFCC/ATCA, Subject; Proposed Revision of Material Requirements for Taxiway and Apron Markings, 20 Jul 92.

6. USAFIFC/IP Letter to HQ AFCESA/DM, Subject; Proposed Revision of Material Requirements for Taxiway and Apron Markings, 28 Jul 92.

7. HQ AFCESA/DMP Memo for Record regarding the telephone conversation between Mr Michael Ates and SMSgt Roger Maurais, HQ AFSA/SEFA, Subject; Proposed Revision of Material Requirements for Taxiway and Apron Markings, 4 Aug 92.

8. HQ AFCC/AT Letter to HQ AFCESA/DM, Subject; Proposed Revision of Material Requirements for Taxiway and Apron Markings, 28 Jul 92.

9. HQ USAF/CEVP Letter to HQ AFCESA/DMP, Subject; Proposed Revision of Material Requirements for Taxiway and Apron Markings, 10 Aug 92.

10. HQ AFCESA/DM Letter to All USAF Major Commands, Subject; Revision of Material Requirements for Reflectorizing Taxiway and Apron Markings, 6 Aug 92.

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14. Federal Specification TT-B-1325C, Beads (Glass Spheres) Retro-reflective, June 1, 1993.

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17. Navy Public Works Center, San Francisco Bay Area Specification PWC-DS-1952-B, Paint, Traffic and Airfield Marking, Water Base, 30 May 1989.

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APPENDIX A -- TABULATION OF RETROREFLECTIVE VALUES

PHASE I

DATE: 15 June 92
DATA COLLECTED AT: Ellsworth AFB SD
LOCATION: North End of Taxiway A, Test Stripes 1 and 2.
PERIOD COVERED: 28 Sep 91 through 9 Jun 92

Retroreflectivity readings were taken in this area for the purpose of determining the rate of degradation and to allow comparison of the two types of media used to reflectorize pavement markings. Test Stripe One was reflectorized using 1.5 Index of Refraction glass beads and Test Stripe Two with 1.9 Index of Refraction glass beads. All readings were taken with a Mirolux 12 Retroreflectometer, S/N 214, beginning at the north end of taxiway A and at successive increments of approximately 200 feet. The pavement was spot marked adjacent to the location where the initial readings were taken and all subsequent readings were taken at those same locations. Readings are expressed in Mirolux 12 Units.

Test Stripe One (1.5 IOR Glass Beads)		
28/09/91	*14/11/91	9/06/92
242	90	190
169	115	190
236	166	217
222	181	220
229	190	142
192	121	180
191	117	155
174	161	182
193	131	174
205 Avg	*141 Avg	183 Avg
Std Dev	Std Dev	Std Dev
27	34	25
Median	Median	Median
193	131	182

Test Stripe Two (1.9 IOR Glass Beads)		
28/09/91	*14/11/91	9/06/92
629	138	119
410	129	111
252	175	106
515	253	117
380	205	120
403	140	118
415	200	116
319	193	118
582	179	112
434 Avg	*179 Avg	128 Avg
Std Dev	Std Dev	Std Dev
121	40	5
Median	Median	Median
410	179	117

*The retroreflective values of the test stripes recorded in November were inconsistent with respect to the total amount of degradation occurring over the life of the marking. There are two possible explanations for this disparity. First, the pavement was wet when the measurements were made on 14 Nov 91. This condition causes much of the light which would normally be reflected by the smaller diameter spheres to bend prematurely and not reflect into the optics of the instrument. This will cause the readings to be lower than normal. Second, the gradation of the 1.5 IOR media is smaller and more uniform than that of the 1.9 IOR media so more of the spheres are completely covered with paint initially. Surface abrasion from tires or other means such as snow removal operations later exposes the smaller diameter spheres which improves the reflectivity of the marking.

APPENDIX B - PILOT QUESTIONNAIRE RESULTS

PHASE I

All aircraft commanders surveyed were asked to complete the survey upon debrief. The test stripes and their location were described to the aviators but they were not informed which stripe was reflectorized with traffic or airfield beads. They were given four subjective options for evaluation of each stripe; "Excellent/Good/Fair/Poor". Survey results were compiled according to pilot preference and the totals for each response. The pilot preference totals have been sub-totaled according to the date the surveys were collected. This method of tabulation demonstrates the comparative rate of degradation.

Pilot's Indicated Preference

Questionnaire Collection Date	Test Stripe 1 (1.5 IOR Beads)	Test Stripe Two (1.9 IOR Beads	No Preferenc
31 Oct 91	9	7	22
21 Nov 91	4	5	8
2 Jan 92	3	0	8
30 Mar 92	6	1	5
8 Jun 92	5	1	5
Totals	27 (30%)*	14 (15%)*	48 (53%)

* The 89 questionnaires demonstrated above represent 98% of those collected. Two of the surveys collected during the 21 Nov to 2 Jan time frame indicated the pilot could not perform a comparison due to snow completely covering the test stripes. These represent the remaining 2% of the questionnaires collected. Totals appearing in the "No Preference Indicated" column, rated only one test stripe, or rated both test stripes equally.

Rating Totals

	Test Stripe One (1.5 IOR Beads)	Test Stripe Two (1.9 IOR Beads)
Excellent	29 (32%)	20 (22%)
Good	36 (40%)	43 (47%)
Fair	13 (14%)	14 (15%)
Poor	6 (7%)	6 (7%)
*Not Indicated	7 (7%)	8 (9%)
Totals	91 (100%)	91 (100%)

*Rating Not Indicated: Two of the responses indicated rating was not possible since the test stripes were completely covered with snow. Three pilots provided comments indicating their preference for Test Stripe 1 or Test Stripe 2 but did not rate either stripe as indicated above. Two pilots indicated they could see no difference and did not rate either stripe. One Pilot rated Test Stripe 1 only.

APPENDIX C -- TABULATION OF RETROREFLECTIVE VALUES

PHASE II

Retroreflectivity Readings -- Runway 13L, North Side -- 12 & 28 Dec 93

1.5 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 13L, North Side, 1.5 IOR beads
S-1 - Inside -- S-6 - Outside
Total Readings -- 36

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	224	233	226	249	284	236	1452	242
S-2	256	328	201	274	327	236	1622	270
S-3	180	210	261	237	197	225	1310	218
S-4	236	220	203	298	303	188	1448	241
S-5	218	312	295	245	268	217	1555	259
S-6	229	274	247	292	310	294	1646	274
Total of all 1.5 IOR threshold readings --							9033	
Average of all 1.5 IOR threshold readings --								251

Fixed Distance Marking -- Runway 13L, 1.5 IOR Beads
(Six readings each side, taken four feet inboard.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	362	263	315	193	174	278	1585	264
Outside	294	213	344	295	318	227	1691	282
Total of all 1.5 IOR fixed distance readings --							3276	
Average of all 1.5 IOR fixed distance readings --								273

Touchdown Zone Marking -- Runway 13L, at 1,500', 1.5 IOR Beads
(Six readings each stripe -- inside to outside.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	257	252	234	310	312	298	1663	277
Outside	240	332	302	300	338	239	1751	292
Total of all 1.5 IOR touchdown zone marking readings --							3414	
Average of all 1.5 IOR touchdown zone marking readings --								285

Centerline Stripes -- Runway 13L, at 7,000 DTG, 1.5 IOR Beads
(Six readings each stripe -- three stripes)
Total Readings -- 18

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	251	242	308	488	333	355	1977	330
S-2	206	193	173	240	213	293	1318	220
S-3	258	233	237	287	282	206	1503	251
Total of all 1.5 IOR centerline stripes --							4798	
Average of all 1.5 IOR centerline stripes --								267

Total Value of All Readings Combined --	20521
Total Number of Readings --	78
Average Reading --	263
Standard Deviation --	53
Median --	254

Retroreflectivity Readings -- Runway 31R, South Side -- 12 & 28 Dec 93

1.9 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 31R, South Side, 1.9 IOR beads
S-1 - Inside -- S-6 - Outside **Total Readings -- 36**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	436	427	675	514	427	638	3117	520
S-2	497	581	570	595	590	348	3181	530
S-3	483	561	543	420	501	439	2947	491
S-4	336	622	572	619	501	484	3134	522
S-5	538	496	443	409	540	499	2925	488
S-6	570	542	641	463	740	582	3538	590
Total of all 1.9 IOR threshold readings --							18842	
Average of all 1.9 IOR threshold readings --								523

Fixed Distance Marking -- Runway 31R, 1.9 IOR Beads
(Six readings each side, taken four feet inboard.) **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	667	531	336	350	471	545	2900	483
Outside	465	493	690	650	639	587	3524	587
Total of all 1.9 IOR fixed distance readings --							6424	
Average of all 1.9 IOR fixed distance readings --								535

Touchdown Zone Marking -- Runway 31R, at 1,500', 1.9 IOR Beads
(Six readings each stripe -- inside to outside.) **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	464	546	482	490	573	560	3115	519
Outside	591	459	544	685	504	497	3280	547
Total of all 1.9 IOR touchdown zone marking readings --							6395	
Average of all 1.9 IOR touchdown zone marking readings --								533

Centerline Stripes -- Runway 31R, at 7,000 DTG, 1.9 IOR Beads
(Six readings each stripe -- three stripes) **Total Readings -- 18**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	605	662	468	588	528	655	3506	584
S-2	612	663	665	466	437	537	3380	563
S-3	570	556	460	698	532	740	3556	593
Total of all 1.9 IOR centerline stripes --							10442	
Average of all 1.9 IOR centerline stripes --								580

Total Value of All Readings Combined --	42103
Total Number of Readings --	78
Average Reading --	540
Standard Deviation --	92
Median --	541

Retroreflectivity Readings -- Runway 13L, North Side -- 5 May 94

1.5 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 13L, 1.5 IOR beads
S-1 - Inside -- S-6 - Outside
Total Readings -- 36

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	310	297	336	278	321	249	1791	299
S-2	235	342	344	310	346	278	1855	309
S-3	318	278	283	289	315	279	1762	294
S-4	300	330	290	303	304	259	1786	298
S-5	271	287	245	209	425	365	1802	300
S-6	281	357	298	333	303	283	1855	309
Total of all 1.5 IOR threshold readings --							10851	
Average of all 1.5 IOR threshold readings --								301

Fixed Distance Marking -- Runway 13L, 1.5 IOR Beads
(Six readings each side, taken four feet inboard.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	257	255	262	257	220	193	1444	241
Outside	328	316	363	228	306	374	1915	319
Total of all 1.5 IOR fixed distance readings --							3359	
Average of all 1.5 IOR fixed distance readings --								280

Touchdown Zone Marking -- Runway 13L, at 1,500', 1.5 IOR Beads
(Six readings each stripe -- inside to outside.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	406	371	260	356	394	178	1965	328
Outside	313	186	274	352	379	365	1869	312
Total of all 1.5 IOR touchdown zone marking readings --							3834	
Average of all 1.5 IOR touchdown zone marking readings --								320

Centerline Stripes -- Runway 13L, at 7,000 DTG, 1.5 IOR Beads
(Six readings each stripe -- three stripes)
Total Readings -- 18

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	375	255	238	314	336	343	1861	310
S-2	353	402	344	338	342	267	2046	341
S-3	301	273	351	356	323	330	1934	322
Total of all 1.5 IOR centerline stripes --							5841	
Average of all 1.5 IOR centerline stripes --								325

Total Value of All Readings Combined --	23885
Total Number of Readings --	78
Average Reading --	306
Standard Deviation --	52
Median --	308

Retroreflectivity Readings -- Runway 31R, South Side -- 5 May 94

1.9 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 31R, 1.9 IOR beads

S-1 - Inside -- S-6 - Outside — **Total Readings -- 36**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	666	668	653	557	470	550	3564	594
S-2	426	480	687	755	620	769	3737	623
S-3	559	557	657	602	654	676	3705	618
S-4	511	549	563	591	508	659	3381	564
S-5	485	532	504	565	498	479	3063	511
S-6	430	501	525	592	573	638	3259	543
Total of all 1.9 IOR threshold readings --							20709	
Average of all 1.9 IOR threshold readings --								575

Fixed Distance Marking -- Runway 31R, 1.9 IOR Beads

(Six readings each side, taken four feet inboard.) — **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	578	496	767	625	537	681	3684	614
Outside	580	556	672	610	574	593	3585	598
Total of all 1.9 IOR fixed distance readings --							7269	
Average of all 1.9 IOR fixed distance readings --								606

Touchdown Zone Marking -- Runway 31R, at 1,500', 1.9 IOR Beads

(Six readings each stripe -- inside to outside.) — **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	581	487	552	393	550	442	3005	501
Outside	650	465	374	539	609	406	3043	507
Total of all 1.9 IOR touchdown zone marking readings --							6048	
Average of all 1.9 IOR touchdown zone marking readings --								504

Centerline Stripes -- Runway 31R, 420' prior to 7,000 DTG, 1.9 IOR Beads

(Six readings each stripe -- three stripes) — **Total Readings -- 18**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	689	596	552	675	616	394	3522	587
S-2	679	676	309	640	593	777	3674	612
S-3	539	655	580	632	572	549	3527	588
Total of all 1.9 IOR centerline stripes --							10723	
Average of all 1.9 IOR centerline stripes --								596

Total Value of All Readings Combined --	44749
Total Number of Readings --	78
Average Reading --	574
Standard Deviation --	94
Median --	574

Retroreflectivity Readings -- Runway 13L, North Side -- 27 Oct 94

1.5 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 13L, 1.5 IOR beads
S-1 - Inside -- S-6 - Outside
Total Readings -- 36

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	360	367	384	350	306	332	2099	350
S-2	214	344	366	377	381	357	2039	340
S-3	327	344	361	357	345	348	2082	347
S-4	345	327	361	326	309	220	1888	315
S-5	382	342	379	322	391	392	2208	368
S-6	428	431	390	363	337	383	2332	389
Total of all 1.5 IOR threshold readings --							12648	
Average of all 1.5 IOR threshold readings --								351

Fixed Distance Marking -- Runway 13L, 1.5 IOR Beads
(Six readings each side, taken four feet inboard.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	241	315	306	234	274	198	1568	261
Outside	279	291	279	313	319	258	1739	290
Total of all 1.5 IOR fixed distance readings --							3307	
Average of all 1.5 IOR fixed distance readings --								276

Touchdown Zone Marking -- Runway 13L, at 1,500', 1.5 IOR Beads
(Six readings each stripe -- inside to outside.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	286	292	251	261	270	295	1655	276
Outside	283	319	313	215	297	278	1705	284
Total of all 1.5 IOR touchdown zone marking readings --							3360	
Average of all 1.5 IOR touchdown zone marking readings --								280

Centerline Stripes -- Runway 13L, at 7,000 DTG, 1.5 IOR Beads
(Six readings each stripe -- three stripes)
Total Readings -- 18

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	321	353	342	306	290	320	1932	322
S-2	288	291	292	271	322	275	1739	290
S-3	370	429	349	338	305	300	2091	349
Total of all 1.5 IOR centerline stripes --							5762	
Average of all 1.5 IOR centerline stripes --								320

Total Value of All Readings Combined --	25077
Total Number of Readings --	78
Average Reading --	322
Standard Deviation --	50
Median --	322

Retroreflectivity Readings -- Runway 31R, South Side -- 27 Oct 94

1.9 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 31R, 1.9 IOR beads
S-1 - Inside -- S-6 - Outside — **Total Readings -- 36**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	810	696	744	639	457	719	4065	678
S-2	580	329	486	592	577	557	3121	520
S-3	505	412	527	664	748	757	3613	602
S-4	626	617	648	670	585	591	3737	623
S-5	629	750	641	626	710	640	3996	666
S-6	462	605	678	699	617	731	3792	632
Total of all 1.9 IOR threshold readings --							22324	
Average of all 1.9 IOR threshold readings --								620

Fixed Distance Marking -- Runway 31R, 1.9 IOR Beads
(Six readings each side, taken four feet inboard.) — **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	723	669	603	653	568	651	3867	645
Outside	532	424	607	675	725	544	3507	585
Total of all 1.9 IOR fixed distance readings --							7374	
Average of all 1.9 IOR fixed distance readings --								615

Touchdown Zone Marking -- Runway 31R, at 1,500', 1.9 IOR Beads
(Six readings each stripe -- inside to outside.) — **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	584	492	454	481	509	531	3051	509
Outside	543	569	499	552	550	469	3182	530
Total of all 1.9 IOR touchdown zone marking readings --							6233	
Average of all 1.9 IOR touchdown zone marking readings --								519

Centerline Stripes -- Runway 31R, at 420' prior to 7,000 DTG, 1.9 IOR Beads
(Six readings each stripe -- three stripes) — **Total Readings -- 18**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	384	689	510	527	719	627	3456	576
S-2	504	725	597	730	583	628	3767	628
S-3	498	484	344	566	424	752	3068	511
Total of all 1.5 IOR centerline stripes --							10291	
Average of all 1.5 IOR centerline stripes --								572

Total Value of All Readings Combined --	46222
Total Number of Readings --	78
Average Reading --	593
Standard Deviation --	105
Median --	595

Retroreflectivity Readings -- Runway 13L, North Side -- 24 Mar 95

1.5 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 13L, North Side, 1.5 IOR beads
S-1 - Inside -- S-6 - Outside
Total Readings -- 36

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	360	372	359	302	350	309	2052	342
S-2	319	407	355	350	379	369	2179	363
S-3	295	350	311	337	336	234	1863	311
S-4	315	282	329	394	325	393	2038	340
S-5	356	340	366	464	335	312	2173	362
S-6	331	360	331	406	424	349	2201	367
Total of all 1.5 IOR threshold readings --							12506	
Average of all 1.5 IOR threshold readings --								347

Fixed Distance Marking -- Runway 13L, 1.5 IOR Beads
(Six readings each side, taken four feet inboard.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	301	279	254	264	377	335	1810	302
Outside	352	319	338	362	344	365	2080	347
Total of all 1.5 IOR fixed distance readings --							3890	
Average of all 1.5 IOR fixed distance readings --								324

Touchdown Zone Marking -- Runway 13L, at 1,500', 1.5 IOR Beads
(Six readings each stripe -- inside to outside.)
Total Readings -- 12

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	224	224	301	341	329	294	1713	286
Outside	274	342	313	308	373	347	1957	326
Total of all 1.5 IOR touchdown zone marking readings --							3670	
Average of all 1.5 IOR touchdown zone marking readings --								306

Centerline Stripes -- Runway 13L, at 7,000 DTG, 1.5 IOR Beads
(Six readings each stripe -- three stripes)
Total Readings -- 18

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	312	345	349	375	324	351	2056	343
S-2	319	339	273	360	362	257	1910	318
S-3	428	413	436	362	299	333	2271	379
Total of all 1.5 IOR centerline stripes --							6237	
Average of all 1.5 IOR centerline stripes --								347

Total Value of All Readings Combined --	26303
Total Number of Readings --	78
Average Reading --	337
Standard Deviation --	46
Median	340

Retroreflectivity Readings -- Runway 31R, South Side -- 24 Mar 95

1.9 IOR Beads (NOTE: S = Stripe -- R = Reading)

Threshold Markings -- Runway 31R, South Side, 1.9 IOR beads
S-1 - Inside -- S-6 - Outside **Total Readings -- 36**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	497	461	585	513	552	497	3105	518
S-2	597	781	742	771	801	850	4542	757
S-3	761	640	759	716	729	765	4370	728
S-4	533	520	499	714	576	510	3352	559
S-5	762	810	917	841	913	816	5059	843
S-6	625	795	619	776	728	700	4243	707
Total of all 1.9 IOR threshold readings --							24671	
Average of all 1.9 IOR threshold readings --								685

Fixed Distance Marking -- Runway 31R, 1.9 IOR Beads
(Six readings each side, taken four feet inboard.) **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	602	694	629	653	630	664	3872	645
Outside	708	678	715	605	599	552	3857	643
Total of all 1.9 IOR fixed distance readings --							7729	
Average of all 1.9 IOR fixed distance readings --								644

Touchdown Zone Marking -- Runway 31R, at 1,500', 1.9 IOR Beads
(Six readings each stripe -- inside to outside.) **Total Readings -- 12**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
Inside	469	661	508	461	543	525	3167	528
Outside	597	577	558	519	598	507	3356	559
Total of all 1.9 IOR touchdown zone marking readings --							6523	
Average of all 1.9 IOR touchdown zone marking readings --								544

Centerline Stripes -- Runway 31R at 420' prior to 7,000 DTG, 1.9 IOR Beads
(Six readings each stripe -- three stripes) **Total Readings -- 18**

	R-1	R-2	R-3	R-4	R-5	R-6	Totals	Averages
S-1	399	410	510	469	711	700	3199	533
S-2	585	646	678	393	508	472	3282	547
S-3	336	401	705	578	688	680	3388	565
Total of all 1.9 IOR centerline stripes --							9869	
Average of all 1.9 IOR centerline stripes --								548.2778

Total Value of All Readings Combined --	48792
Total Number of Readings --	78
Average Reading --	626
Standard Deviation --	128
Median	622

APPENDIX D -- PILOT QUESTIONNAIRE RESULTS

PHASE II

A/C Type & Number of Evaluations		Month and Year of Evaluations			Approach Used	
					13L	31R
F-15	24	Feb-94	6			6
		Apr-94	1		1	
		Aug-94	5			5
		Nov-94	1			1
		Feb-95	11		1	10
		Total F-15	24		2	22
F-16	5	Jan-94	4		2	2
		Mar-94	1			1
		Total F-16	5		2	3
T-37	2	Mar-94	1			1
		Dec-94	1		1	
		Total T-37	2		1	1
C-130	1	Apr-94	1		1	
C-9	1	Apr-94	1		1	
TA-4	1	Dec-94	1			1
C-172	1	Aug-94	1		1	

Combined A/C Survey Dates		
Jan-94	4	
Feb-94	6	
Mar-94	2	
Apr-94	3	
Aug-94	6	
Nov-94	1	
Dec-94	2	
Feb-95	11	

Total Surveys Accomplished	35

With respect to centerline, which side of the threshold, touchdown zone and fixed distance markings did not provide an adequate level of reflectivity?

Note: This question asked the pilots to provide information relative to the location of any markings that did not appear as adequate for the intended purpose. The responses shown here reflect the type of beads used to reflectorize the markings they identified.

	1.5 IOR Markings		1.9 IOR Markings	No Difference	No Response
During approach	1 or 3%*		0	33 or 94%	1 or 3%
After touchdown	1 or 3%*		0	33 or 94%	1 or 3%

*NOTE: The pilot indicated the markings on the left side of runway 13L did not provide an adequate level of reflectivity. This evaluation was performed at 1200 hours central on 7 Jan 94.

Was there a noticeable difference in the appearance of any section of the centerline stripes?

Yes	*3 or 9%

No	32 or 91%

* Three surveys indicated there was a noticeable difference in some of the centerline stripes. The pilot's comments are provided below.

1. An F-15 pilot completed two separate surveys, on two separate dates, indicating both times that the centerline stripes were "not very visible until close to the runway." He also indicated that he couldn't remember which were better or worse. He flew 31R under night VFR at 2145 hours on 22 and 23 Aug 94.

2. The C-130 pilot commented; "Markings starting to be covered w/rubber which may explain why markings 2 - 3,000 feet down runway were brighter." This evaluation was performed on 13L under day VFR at 1637 hours on 9 Apr 94.

If you answered yes above, please indicate the approximate locations of the section(s) of centerline stripes you felt were the least effective. (Circle or block in the numbers below which coincide with the approximate location(s) of the centerline stripes with respect to the distance-to-go markers.)

Note: No specific section of centerline stripes were identified as better or worse except the stripes in the touchdown zone identified by the C-130 pilot as noted above.

What was the time of day and weather condition at the time of your arrival or departure?								
Night VFR	20	or 57%	Night VFR W/Rain	6	or 17%	Day VFR	9	or 26%

Were your landing/taxi lights working properly?			
No Response	3	Yes	31
Not Applicable	1	No	0

If arriving, what type approach did you fly?
Data collected here is deceptive because many pilots indicated more than one approach.

Precision Instrument	27	Non-Precision Inst	10
Day VFR	8	Night VFR	14

Comments (optional):

1. "Really Neat."

2. "Both sets of stripes/marks equally stink."

3. "No difference noted."

4. "Picked up fixed distance markings at 5 NM from touchdown (6 DME), touchdown zone markings @ 4NM from TD (5DME), threshold and centerline @ 3 NM (4 DME). Markings starting to be covered with rubber which may explain why markings 2,000 to 3,000 feet down runway were brighter. Observer sitting in jump seat of C-130 confirmed observations with flight crew."

5. "Ground crew and base ops are excellent."

6. "High cross winds/wind shear did not allow me sufficient time to analyze the two different types of paint markings."

7. "I could tell the difference between the left and right runway."